Design Procedures for Soil Modification or Stabilization

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1.0 General

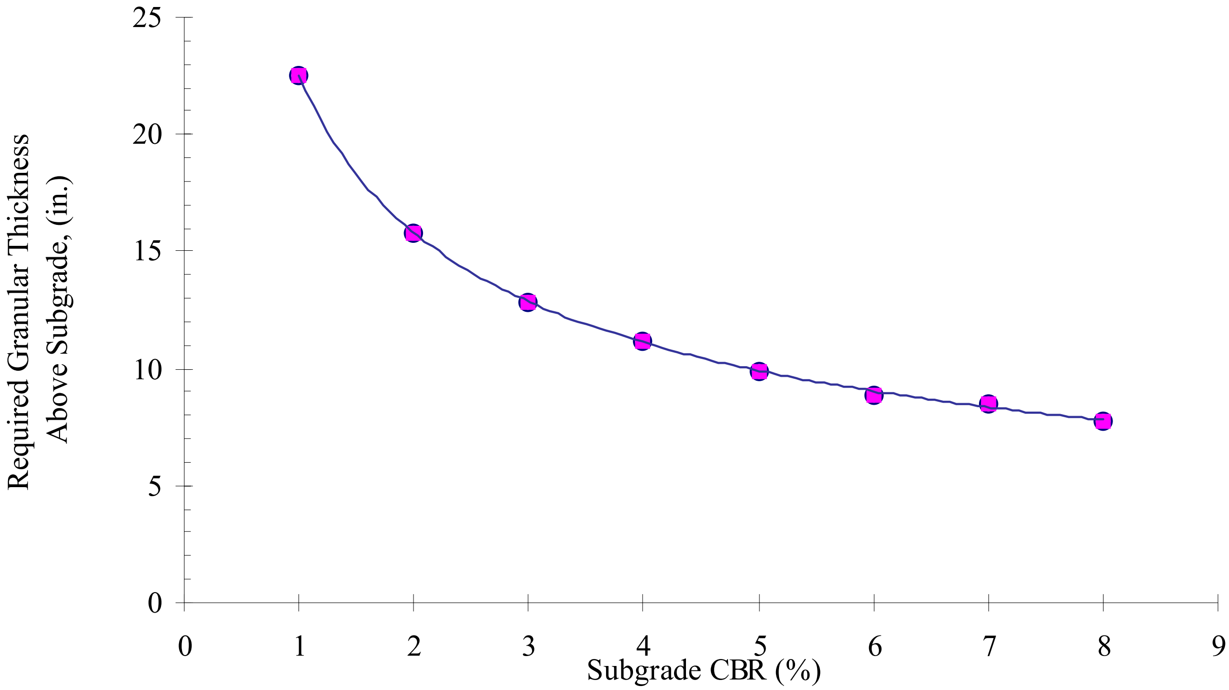
It is the policy of the Indiana Department of Transportation to minimize the disruption of traffic patterns and the delay caused today's motorists whenever possible during the construction or reconstruction of the State's roads and bridges. INDOT Engineers are often faced with the problem of constructing roadbeds on or with soils, which do not possess sufficient strength to support wheel loads imposed upon them either in construction or during the service life of the pavement. It is, at times, necessary to treat these soils to provide a stable subgrade or a working platform for the construction of the pavement. The result of these treatments are that less time and energy is required in the production, handling, and placement of road and bridge fills and subgrades and therefore, less time to complete the construction process thus reducing the disruption and delays to traffic.

These treatments are generally classified into two processes, soil modification or soil stabilization. The purpose of subgrade modification is to create a working platform for construction equipment. No credit is accorded this modification in the pavement design process. The purpose of subgrade stabilization is to enhance the strength of the subgrade and this increased strength is taken into account in the pavement design process. Stabilization requires more thorough design methodology during construction than does modification. The methods of subgrade modification or stabilization include physical processes such as soil densification, blending with granular material, use of reinforcement (Geogrids), undercutting and replacement, etc., and chemical processes such as mixing with cement, fly ash, lime and lime by-products, etc. Soil properties such as strength, compressibility, hydraulic conductivity, workability, swelling potential, and volume change tendencies may be altered by various soil modification or stabilization methods.

Subgrade modification shall be considered for all soils with natural moisture content greater than their optimum moisture content. Soil modification shall be considered for all projects. When used, modification or stabilization shall be required for the full roadbed width including shoulders or curbs. Subgrade stabilization shall be considered for all subgrade soils with a CBR < 2.

INDOT standard specifications provide the contractor options on construction practices to achieve subgrade modification that includes chemical modification, replacement with compacted aggregates, and density and moisture controls. Geotechnical designers have to evaluate the needs of the subgrade and include where necessary, specific treatment above and beyond the standard specifications. Designers may also include geosynthetic stabilization when standard treatments are not sufficient.

Various soil modification or stabilization guidelines are discussed below. It is necessary for designers to take into consideration the local economic factors as well as environmental conditions and project location in order to make prudent decisions for design. It is important to note that modification and stabilization terms are not interchangeable.



Required Thickness Above Subgrade vs. Subgrade CBR
Figure 1.0A

2.0 Modification or Stabilization of Soils

2.01 Mechanical Modification or Stabilization

This is the process of altering soil properties by changing the gradation through mixing with other soils, densifying the soils using compaction efforts, or undercutting the existing soils and replacing them with granular material.

A common remedial procedure for wet and soft subgrade is to cover it with granular material or to partially remove and replace the wet subgrade with a granular material to a pre-determined depth below the grade lines. The compacted granular layer distributes the wheel loads over a wider area and serves as a working platform. (1)

To provide a firm-working platform with granular material, the following conditions shall be met.

1. The thickness of the granular material must be sufficient to develop acceptable pressure distribution over the wet soils.

2. The backfill material must be able to withstand the wheel load without rutting.

3. The compaction of the backfill material should be in accordance with the Standard Specifications.

Based on past experience, usually 6 to 12 in. (150 to 300 mm) of granular material should be adequate for subgrade stabilization. However, deeper undercut and replacement may be required in certain areas.

The undercut and backfill option is widely used for construction traffic mobility and a working platform. This option could be used either on the entire project or as a spot treatment. The equipment needed for construction is normally available on highway construction projects.

2.02 Geosynthetic Stabilization

2.03 Chemical Modification or Stabilization

The transformation of soil index properties by adding chemicals such as cement, fly ash, lime, or a combination of these, often alter the physical and chemical properties of the soil including the cementation of the soil particles. There are the two primary mechanisms by which chemicals alter the soil into a stable subgrade:

1. General increase in particle size by cementation, reduction in plasticity index, hydraulic conductivity, and shrink/swell potential.

2. Absorption and chemical binding of moisture that will facilitate compaction.

3.0 Design Procedures

3.01 Reactive Soils for Stabilization

The reaction of a soil-lime or a soil-cement mixture is important for stabilization and design methodology and shall be based on an increase in the unconfined compression strength test data. To determine the reactivity of the soils for lime-stabilization, a pair of specimens of 2 in. (50 mm) diameter by 4 in. (100 mm) height (after mixing at least 5% lime by dry weight of the natural soil) is prepared at the optimum moisture content and maximum dry density (AASHTO T 99). These specimens are cured for 48 hours at 120^{o} F (50^{o} C) in the laboratory and tested as per AASHTO T 208. The strength gain of lime-soil mixture must be at least 50 psi (350 kPa) greater than the natural soils. A strength gain of 100 psi (700 kPa) of a soil-cement mixture over the natural soil shall be considered adequate for cement stabilization with 3% cement by dry weight of soils and tested as described above.

In case of soils modification, enhanced subgrade support is not accounted for in pavement design. Therefore, guidelines 3.02(2) shall be used to provide a working platform or required compaction.

3.02 Criteria for Chemical Selection

When the chemical stabilization or modification of subgrade soils is considered as the most economical or feasible alternate, the following criteria should be considered for chemical selection based on index properties of the soils. (2)

1. Chemical Selection for Stabilization.

    a. Lime: If PI > 10 and minimum clay content (2μ) > 10%.

    b. Cement: If PI ≤ 10 and percentage passing No. 200 < 20%.

    c. Lime, cement, or fly ash combination.

    If soils are less than 10% passing No. 200, and the plasticity index range is 10 < PI < 20.

2. Chemical Selection for Modification

    a. Lime: % Passing No. 200 > 35 and PI > 5

    b. Cement or Fly ash: % Passing No. 200 ≤ 35 and PI < 5

    Note: Cement and fly ash may be considered as a combination.

    Appropriate tests showing the improvements are essential for the exceptions listed above.

3.03 Suggested Chemical Quantities

1. Lime or Lime By-Products: 3% to 9%

2. Cement: 3% to 10%

3. Fly ash: 10% to 25%

4.0 Laboratory Test Requirements

1. Soil Sampling. An approved Geotechnical Engineer should visit the project during the construction and collect a bag sample of each type of soil in sufficient quantity for performing the specified tests. The geotechnical engineer should review the project geotechnical report and other pertinent documents, including soil maps, etc. prior to the field visit. The geotechnical consultant shall submit the test results and recommendations, along with the current material safety data sheet or mineralogy to INDOT for approval. If the geotechnical engineer determines the necessity of chemical-soil stabilization during the design phase, they should design a subgrade treatment utilizing the chemical in the geotechnical report based on INDOT guidelines.

2. Lime or Lime By-Products Required for Modification or Stabilization. The following procedures shall be utilized to determine the amount of lime required to stabilize the subgrade. Hydrated lime or quicklime and lime by-products can be used in the range of 4 ± 0.5% and 5 ± 1% by weight of soil for modification respectively. The following procedures shall be used to determine the optimum lime content. (3)

a. Perform mechanical and physical tests on the soils.

b. Determine the separate pH of soil and lime samples.

c. Determine optimum lime content using Eades and Grim pH test.

   The sufficient amount of lime may be added to soils to produce a pH of 12.4 or equal to a pH of lime itself and a graph is plotted between pH and lime percentage. Optimum lime content shall be determined corresponding to the maximum pH of lime-soil mixture. (See Figure 4.0 A).

   - Representative samples of air-dried, minus No. 40 soil is equal 20 gm of oven-dried soil are weighed to the nearest 0.1 gm and poured into 150-ml (or larger) plastic bottles with screw tops.

   - It is advisable to set up five bottles with lime percentages of 3, 4, 5, 6, 7. This will insure, in most cases, that the percentage of lime required can be determined in one hour. Weigh the lime to the nearest 0.01 gm and add it to the soil. Shake to mix soil and dry lime.

   - Add 100 ml of CO_2-free distilled water to the bottles.

   - Shake the soil-lime and water until there is no evidence of dry material on the bottom. Shake for a minimum of 30 seconds.

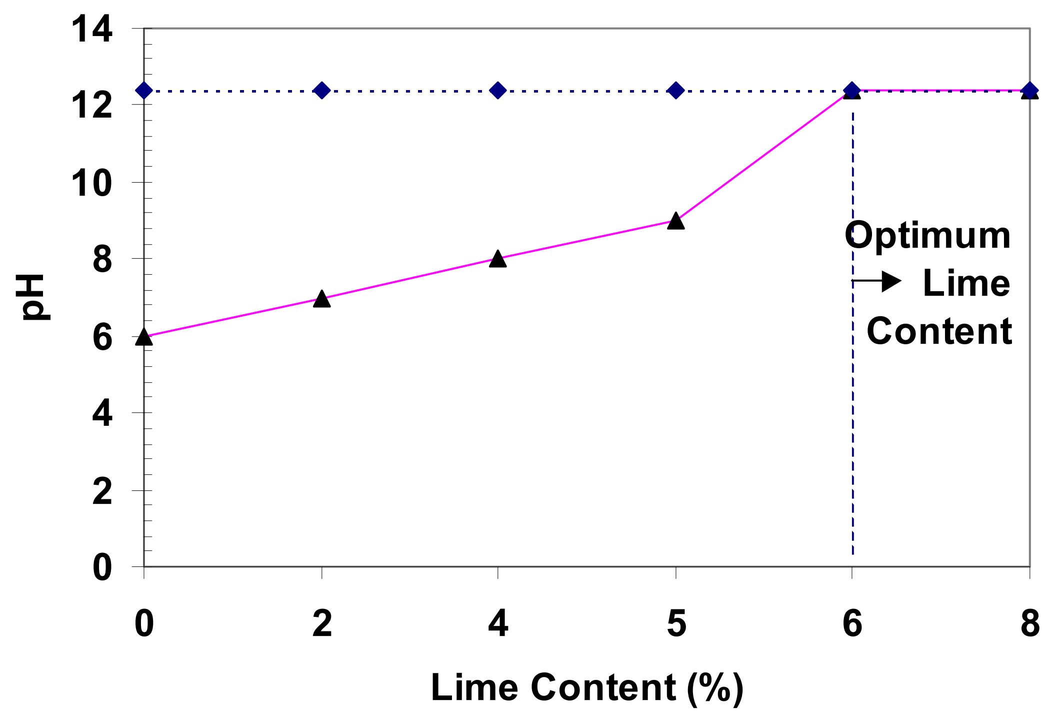
   - Shake the bottles for 30 seconds every 10 minutes.

   - After one hour, transfer part of the slurry to a plastic beaker and measure the pH. The pH meter must be equipped with a Hyalk electrode and standardized with a buffer solution having a pH of 12.00.

   - Record the pH for each of the lime-soil mixtures. If the pH readings go to 12.40, the lowest percent lime that gives a pH of 12.40 is the percent required to stabilize the soil. If the pH did not go beyond 12.30 and 2 percent lime gives the same reading, the lowest percent which gives a pH of 12.30 is that required to stabilize the soil. If the highest pH is 12.30 and only 1 percent lime gives a pH of 12.30, additional test bottles should be started with larger percentages of lime.

d. Atterberg limit should be performed on soil-lime mixture corresponding to various lime soil mixtures as discussed above.

e. Compaction shall be performed in accordance with AASHTO T 99 on optimum lime and soil mixture to evaluate the drop in maximum dry density in relation to time (depending on the delay between the lime - soil mixing and compaction.)



pH vs. Lime Content
Figure 4.0A

In the case of stabilization, the Unconfined Compression Test and California Bearing Ratio at 95% compaction shall be performed in addition to the above tests corresponding to optimum lime-soil mixture of various predominant soils types.

4.01 <u>Cement Required for Stabilization or Modification</u>

Criteria for cement percentage required stabilization should be as follows. However, there is no test requirement for the optimum cement content. A 4 ± 0.50% of cement can be utilized to modify the subgrade. The following methodology shall be used for quality control and soil - cement stabilization.

1. Perform the mechanical and physical properties of the soils.

2. Select the Cement Content based on the following:

AASHTO Classification	Usual Range In Cement Requirement (% by dry weight of soil)
A-1-a	3 – 5
A-1-b	5 – 8
A-2	5 – 9
A-3	7 - 10

Suggested Cement Contents (4)
Figure 4.0B

3. Perform the Standard Proctor on soil-cement mixture for change in maximum dry unit weight.

4. Perform the unconfined compression and CBR tests on the pair of specimens molded at 95% of the standard Proctor in case of stabilization.

4.02 Fly Ash Required for Modification (5)

1. The in-situ soils should meet the criteria of modifications.

2. Standard Proctor should be performed in accordance with AASHTO T 99 to determine the maximum dry density and optimum moisture content of the soil.

3. The sufficient amount of fly ash (beginning from 10% by dry weight of soil) should be mixed with the soils in increments of at least 5%. The moisture content of the mix shall be in the range of optimum moisture content + 2%, and then each blend of the fly ash soil mixture should be compacted as per the standard proctor to determine the maximum dry density.

4. The compaction of mixes shall be completed within 2 hours.

5. A percentage of fly ash, which provides the maximum dry density, should be considered as the optimum amount of fly ash for that soil.

6. Compressive strength of optimum fly ash mix sample should be determined after 2, 4, and 8 hours after compaction.

7. A pair of specimens of optimum fly ash mix sample should be molded of standard proctor and soaked for 4 days. The swelling should be observed daily. The percentage of swell of more than 3% shall not be allowed.

4.03 Combination of Cement Fly Ash and Lime Mixture

To enhance the effectiveness of lime, cement or fly ash modification or stabilization combinations, the subsequent guidelines shall be used.

1. Lime and Fly ash: The ratio between lime and fly ash mixture should be 1:1 to 1:9 respectively.

2. Cement and Fly ash: The ratio of cement and fly ash should be 1:3 to 1:4 respectively.

3. Lime cement and fly ash combinations may be used in the following proportion of 1:2:4.

5.0 Construction Considerations

Modification of soils such as drying out of wet subgrade with lime, cement and fly ash to speed construction is not as critical as completely stabilizing the soil to be used as a part of the pavement structure. With the growth of chemical modification throughout the state, a variety of applications are being suggested due to such factors as type of soil, percentage of modification/stabilization required, environmental restraints, and availability of chemicals. Furthermore, when chemically stabilized subgrade is used to reduce the overall thickness, the stabilized layer must be built under tight construction specifications, whereas requirements for the construction of working platforms are more lenient. Following are a few recommendations for modification or stabilization of subgrade soils.

(i). Perform recommended tests on each soil to see if the soil will react with chemicals then determine the amount of chemical necessary to produce the desired results.

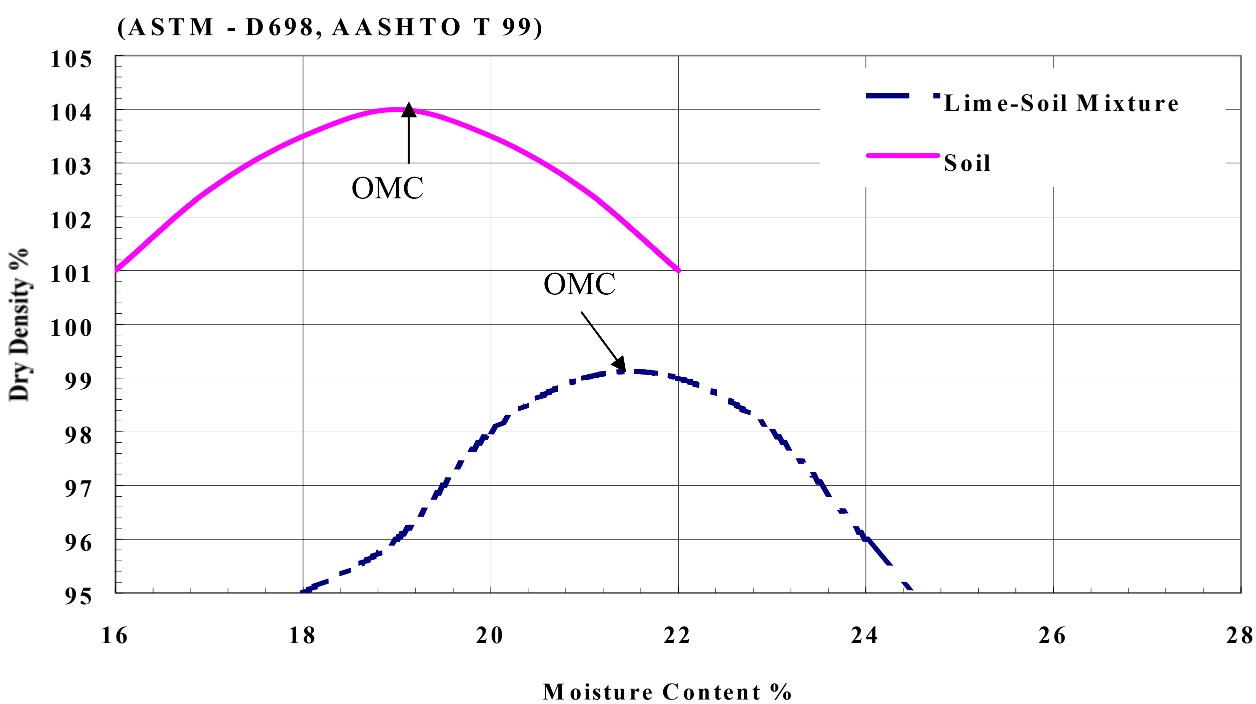
(ii). More chemicals may not give the best results.

(iii). The sulfate, when mixed with calcium will expand. Soils having over 10% sulfate content shall not be mixed with chemicals.

(iv). Chemicals used shall meet the INDOT Standard Specifications.

(v). One increment of chemical is recommended to produce a working platform. Proofrolling is required before placing the base or subbase. Pavement shall not be installed before curing is completed.

(vi). The density of cement treated soils will likely be different than untreated soils. Standard Proctor tests should be performed in the laboratory to estimate the appropriate target density.



Moisture Density Relationship
Figure 5.0A

(vii). Set the grade low to account for the swell in the lime. A swell factor of 10% is an approximate estimate.

(viii). Uniform distribution of chemical, throughout the soil is very important.

(ix). Curing takes 7 days of 50^{o} F + weather for stabilization. No heavy construction equipment should be allowed on the stabilized grade during the curing period.

(x). The maximum dry density of the soil-lime mixture is lower than in untreated soils. Maximum dry density reduction of 3~5 Pcf, is common for a given compactive effort. It is, therefore, it is important that the laboratory for field control purposes provide appropriate density. (See Figure 5.0A).

(xi). Cover the modified or stabilized roadbed with pavement before suspending work for the winter.

(xii). Cement or fly ash treated soils exhibit shrinkage cracks due to soil type, curing, chemical contents, etc. Therefore, it is recommended to provide surface sealing on stabilized subgrade after the curing period.

(xiii). Moisture content of modified or stabilized subgrade should be maintained above the optimum moisture content of modified subgrade during the curing.

(xiv). Lime raises the pH of the soil. Phenolphthalein, a color sensitive indicator solution can be sprayed on the soil to determine the presence of lime. If lime is present, a reddish-pink color develops. (See Figure 5.0B).

Lime Modified Subgrade Uniformity Determination by Phenolphthalein
Figure 5.0B

(xv). Because lime can cause chemical burns, safety gear, such as gloves, etc. shall be used during construction and inspection as well.

References:

1. Thomson, M.R., "Final Report Subgrade Stability" - Civil Engineering Studies, Transportation Engineering Series No. 18, Illinois Cooperative Highway and Transportation Series No. 169, University of Illinois at Urbana - Champaign, 1977.
2. "Air Force Manual of Standard Practice - Soil Stabilization", Draft, U.S. Air Force Academy, 1976.
3. Eades and Grim, "A Quick Test To Determine Lime Requirements For Lime Stabilization", Highway Research Record No. 139, Highway Research Board, Washington, D. C., 1969.
4. Portland Cement Association, "Soil-Cement Inspector's Manual", PA050S, 52 pages, 1963.
5. Zia and Fox, "Engineering Properties Of Loess-Fly-Ash Mixtures For Roadbase Construction", Transportation Research Record 1714, TRB, National Research Council, Washington D. C., 2000.
6. "Soil Stabilization In Pavement Structures", FHWA - 1P. 80-2, Vol. 2, Mixture Design Considerations, FHA, Office of Development Implementation Division, 1979.